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NATIONAL BUREAU OF STANDARDS REPORT

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PERFORMANCE TESTS OF AN ELECTROMAZE
NO. ES-1195 ELECTRIC AIR FILTER

by

Henry E. Robinson
Thomas W. Watson

Report to
General Services Administration
Public Buildings Service
Washington 25, D. C.



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NBS PROJECT

NBS REPORT

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Building Technology Division

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PERFORMANCE TESTS OF AN ELECTROMAZE
NO. ES-1195 ELECTRIC AIR FILTER

1. INTRODUCTION

At the request of the Public Buildings Service, General Services Administration, the performance characteristics of electrostatic air cleaners were determined to provide information to assist in the preparation of new air filter specifications.

The test results presented herein were obtained on a specimen electrostatic filter unit submitted by its manufacturer at the request of the Public Buildings Service and included determinations of dust arresting efficiency with three aerosols (atmospheric air, kerosene lamp smoke, and Cottrell precipitate), pressure drop, specific dirt load and cleanability of the specimen.

2. DESCRIPTION OF THE FILTER SPECIMEN

The cleaner was manufactured by the Air-Maze Corporation, Cleveland 5, Ohio, and was of the electrostatic type. It was identified as an Air-Maze "Electromaze Electric Air Filter" Number ES-1195 with four ES-130 cells, rated velocity 333 feet per minute (1332 CFM total). The power pack had the following nameplate data:

	Power Pack	
Model ES370-030		Serial RC11-3
	Input	
120 Volts	60 cycles	35 VA
	Output	
10 KV		1 MA

The power pack had on its front panel three indicating lamps, one of which was connected in the ionizer or plate circuit. This was a green lamp appearing as a ring of green light with a dark center when voltage was normal (10.3 kv).

The test unit had a housing with actual outside dimensions of $24\text{-}1/4 \times 24\text{-}1/4$ inches and was $32\text{-}1/2$ inches long. It was rated as having 4 sq.ft. of transverse area, i.e., 1332 CFM air delivery at 333 fpm velocity.

The upstream and downstream faces had flanges 30 inches square matching those of the duct of the test apparatus. The face openings were approximately 24 inches square both upstream and downstream. The downstream face was adapted to receive a nominal $30 \times 30 \times 1$ -inch after-filter which for this unit was a $29\text{-}3/8 \times 29\text{-}3/8 \times 7/8$ -inch "Kleenflo" V-crimped screen wire cleanable impingement type air filter manufactured by the Air-Maze Corporation.

There were four similar filter cells in the housing, each having actual outside dimensions of $11\text{-}3/4$ inches in width, 12 inches in height, and $21\text{-}1/2$ inches in length, and each containing 23 aluminum plates spaced approximately $7/16$ -inch apart, presenting a total surface area of approximately 52 square feet for each cell.

The manufacturer furnished an adhesive (a water-emulsifying oil) designated as "Filterkote E Adhesive" for oiling the collecting plates of the cells by spraying them copiously, before inserting the cells into the unit housing. The after-filter was oiled in preparation for the test by spraying the media from the upstream and downstream faces with the same adhesive.

The power pack, connected to a 120-volt 60-cycle supply, was adjusted by the manufacturer's representative to recommended settings prior to the tests; the ionizer and plate voltages that resulted were measured by means of a high-resistance voltmeter which was compared with an accurate electrostatic voltmeter.

3. TEST METHOD AND PROCEDURE

Efficiency determinations were made by the NBS "Dust-Spot Method" using the following aerosols: (a) outdoor air drawn through the laboratory without addition of other dust or contaminant; (b) kerosene lamp smoke and (c) Cottrell precipitate. The test method is described in the paper "A Test Method for Air Filters" by R. S. Dill (ASHVE Transactions, Vol. 44, P.379, 1938). The test duct and arrangement are shown in Figure 1.

A baffle made of two 3-inch wide slats was located in the duct about 3-1/2 ft. downstream of the test unit to inter-mix the air discharged from it.

For these tests, the unit was installed in the test duct and the housing was carefully sealed to prevent in-leakage of air. The desired rate of air flow through the air cleaner was established and samples of air were drawn from the center points of the test duct one foot upstream and eight feet downstream of the air cleaner at equal rates and passed through known areas of Whatman No. 41 filter paper. For the atmospheric air and oil lamp smoke tests, the samples were drawn at equal rates through equal areas of filter paper (3/4-inch diameter spots). The downstream sample was drawn continuously during the test; the upstream sample was drawn intermittently in a number of one-minute periods uniformly distributed over the duration of the test, aggregating one-tenth of the downstream sampling period. Under these conditions an efficiency of 90 percent would be indicated if the upstream and downstream dust-spots on the filter papers had the same opacity, as indicated by the change in the light transmissions of the dust-spot areas before and after the sample was drawn, which were determined by means of a photometer using transmitted light. The filter papers used in the upstream and downstream positions were selected to have the same light transmission readings when clean. If the opacities of the dust-spots differed, the efficiency was calculated by means of the formula.

$$\text{Efficiency, percent} = 100 \left[1 - \frac{t_1}{t_2} \cdot \frac{O_2}{O_1} \right] = 100 - 10 \left(\frac{O_2}{O_1} \right)$$

where O_1 and O_2 were the opacities of the dust-spots upstream and downstream respectively, and t_1 and t_2 were the aggregate times during which the upstream and downstream samples, respectively, were drawn.

For the efficiency tests with Cottrell precipitate as the aerosol the samples upstream and downstream were drawn at equal rates and for equal times but unequal dust-spot areas were used to obtain opacities that were approximately

equal. If the opacities of the dust-spots differed, the value of the efficiency was calculated by means of the formula above, with the ratio A_2/A_1 substituted for the ratios t_1/t_2 , where A_2 and A_1 were the areas of the dust-spots downstream and upstream, respectively.

The following procedure was employed in these tests. After the clean and oiled unit had been installed in the test duct, and all discoverable air leaks into its housing had been sealed, its input and output voltages were adjusted to recommended values by a representative of the manufacturer (input 120 volts; ionizer and plates 10.3 kv). Three determinations of the efficiency of the clean unit were made at the rated velocity, using as the aerosol outdoor air drawn into the test duct through a nearby open window. A determination of efficiency with the unit not energized was also made. Following these, single determinations were made, using outdoor air, at velocities 20 percent greater and 20 percent less than the rated velocity.

Next, three efficiency determinations were made at the rated velocity, using as the aerosol outdoor air with the addition of kerosene smoke generated by an open lamp flame near the inlet to the test duct.

Following these, three efficiency determinations were made at rated velocity, using as an aerosol outdoor air in which was dispersed Cottrell precipitate at a concentration of one gram per thousand cubic feet of air. When these had been obtained, the process was begun of loading the unit with a mixture of 4 percent cotton lint and 96 percent Cottrell precipitate, by weight, separately dispersed into the air stream. The lint used for this purpose was No. 7 cotton linters previously ground in a Wiley mill with a 4-millimeter screen; the lint was dispersed into the air stream through an aspirator operating at approximately 35 psi inlet air pressure. At suitable periods as loading progressed, the efficiency of the unit was determined using 100 percent Cottrell precipitate in outdoor air. In these tests, and during the loading process, the rate of feed of the dispersant was one gram per thousand cubic feet of air. The pressure drop and the ionizer and plate voltages of the unit were recorded at intervals during the tests. The dirt-loading process was continued until about 900 grams of the

lint and Cottrell precipitate mixture had been fed (i.e., 2/3 gram per CFM of unit rating).

At suitable periods as the dirt-loading process progressed, strips of transparent cellulose adhesive tape (3/4 inch wide) were stretched vertically across the test duct near its axis, with the adhesive side facing the air stream. Tapes were located at three positions (1) 12 inches upstream, (2) 15 inches downstream, and (3) 8 feet downstream, of the test unit; the tapes at stations (1) and (3) were in the same longitudinal positions in the test duct as the inlets to the upstream and downstream sampling tubes. The adhesive surface of such a tape captured a sample of the particulate matter in the air flowing past it, and after suitable times of exposure to the aerosol, scrutiny of the tapes by eye and with a microscope afforded considerable information as to the vertical distribution, the nature, number, and size, of the particles caught at the various stations. Photographic enlargements (10X) by transmitted light were made of sections of the tapes corresponding to a position at mid-height in the test duct.

At the end of the tests, one of the filter cells was removed from the test unit and cleaned by means of a stream of cold water from a high pressure hose nozzle, directed at and into the cell plates from both ends of the cell.

4. TEST RESULTS

A summary of the test data, giving efficiencies in percent with the three aerosols and the pressure drop of the complete unit including the after-filter, in inch W.G., at rates of air flow corresponding to various face velocities, is given in Table 1. Also, a summary of the test data obtained in the dirt-loading test conducted at the rated face velocity of 333 fpm is given in Table 2.

Photographs No. 1, 2 and 3 included in this report are 10X enlargements of the center 3/4 x 1-inch sections of cellophane tapes located at the three similarly numbered stations described under Test Method and Procedure. Tapes Nos. 2 and 3 were exposed at their respective stations simultaneously during the dirt-loading test for a period

in which 124 grams of mixture were fed to the test unit. This exposure was during the interval in which the dirt-load increased from 41 to 165 grams, as shown in Table 2. Photograph No. 1 shows a tape exposed at station No. 1 for an equal length of time. After exposure, the tapes were carefully removed from the test duct for photographing and microscopic study.

Throughout the tests with atmospheric air and oil lamp smoke electrical sparking or flashing in the unit audible to the ear occurred one to two times per hour. However, during the Cottrell and lint loading test electrical sparking or flashing occurred fifty to sixty times per minute at the start and throughout the test except during times when the ionizer and plate voltage were low, as evidenced by the voltmeter or by the appearance of the green short-circuit-indicating lamp. Sparking or flashing did not occur when the short-circuit lamp was very dim or completely extinguished.

5. SUMMARY

A. Performance

The efficiency of the air cleaner in arresting the particulate matter existent in atmospheric air drawn through the unit varied considerably with the face velocity at which it was operated, as shown in Table I. At the rated velocity (333 fpm), the average efficiency on atmospheric air (90.2 percent) and that on oil lamp smoke (90.4 percent) were very nearly the same. The efficiencies are reported to three significant figures obtained from the test data. In reporting thus, however, it is considered desirable to point out that an uncertainty on the order of one or two percent is possible in determining efficiencies, although in these results the differences between comparable efficiency values were consistently of a lesser magnitude.

As recorded in Table 2, the ionizer and plate voltage of the unit did not remain steadily at the adjusted value during the course of the dirt-loading test. When the dirt-load had increased to 378 grams, the ionizer and plate voltage was found to have decreased to 8.0 kv from the adjusted value of 10.3 kv. Throughout the remainder of that test-day,

the voltage varied as shown, the first value in each bracket being that at the start of the efficiency determination, and the second that at its end. Voltages during the efficiency determinations were not recorded in detail, consequently the average value through each determination was not ascertained. However, it is evident that the efficiency of the unit in arresting Cottrell precipitate was reduced to some extent by the lowering of ionizer and plate voltage.

During the first day of the loading test, the voltage occasionally dropped below, and later re-attained, its initial adjusted value. A complete recovery of this kind occurred during the over-night shut-down before the second day of loading. However, as loading progressed on the second day, the voltage decreased, until finally just at the end of the loading test, the voltage on the ionizers and plates fell to zero, indicating a complete short-circuit, and thereafter did not rise of itself. On re-energizing the unit on the next day, the voltage rose momentarily to 10.3 kv, several sparkings occurred, and the ionizer and plate voltage thereafter remained at about 6.3 kv. However, it was apparent that the power-pack had not been damaged by the short-circuits experienced. In the unit tested, the green short-circuit light remained illuminated when the ionizer and plate voltages were not lower than about 9.0 kv.

The particular causes of the voltage decrease were not determined, although it was evidently due to the dirt-load on the unit. The electrical insulators were observed to be heavily coated with dust and lint, which may have decreased their resistance markedly; also, as described later under "General", lint fibers bridging the gaps between alternate collecting plates may have assisted in shorting the circuits.

The greater part of the pressure drop through the complete unit was due to the resistance of the after-filter. It is noted in Table 2 that in the dirt-loading test, the pressure drop of the complete unit increased by 0.032 inch W.G. for a total dirt-load of 901 grams. This rise was due chiefly to an increase in the pressure drop of the after-filter, as a result of an accumulation of cotton lint and of comparatively large particles of Cottrell precipitate on its media.

B. Cleanability

After the loading test, one of the four filter cells was removed from the housing and subjected to the cleaning process described under Test Method and Procedure. No difficulty was experienced in thoroughly cleaning the ionizer and collector sections of the unit, using moderate care. The cleanability of the after-filter was not determined, however, filters of this general type have been found in other NBS tests to be readily cleanable by the same method.

C. General

On completion of the dirt-loading test, the filter cells were removed from the unit and examined. The perforated upstream grille, the collector plate surfaces and rods, the insulators and the ionizer supports were all well-covered with Cottrell precipitate and lint deposits. The dust deposits were about 1/32 inch in thickness overall, and were slightly thicker near the leading edges of the collector plates; lint deposits were heavier over the aft areas of the plates. In several areas, the spaces between adjacent collector plates were crossed by bridges of lint fibers; such bridging occurred most extensively in the plate spaces in line downstream from the ionizer bars, and in the spaces bounded on one side by the cell walls. Some lint fibers extended downstream for as much as 1/2 inch from the aft edges of the collector plates.

The upstream face of the after-filter revealed considerable deposits of lint, somewhat concentrated in seven vertical strips about 2-1/2 inches wide, each apparently centered downstream of one of the ionizer wires or bars. The after-filter media was approximately uniformly darkened by a dust deposit on its upstream face, and slightly darkened by dust visible on its downstream face. It was evident that many of the dust particles were relatively large, but because fine particles are less readily observed, it cannot be stated that many fine particles were not also present.

The dirt (dust) deposits on the electrostatic unit, and on the after-filter, appeared to be well-saturated with oil. After the unit had been removed from the test duct, the section downstream of the unit was carefully swept out with a fine brush. The amount of material obtained from the duct by this sweeping was less than one gram.

The cellophane tape samples shown in Photographs Nos. 1, 2 and 3, corresponding to stations (1), (2) and (3), respectively, indicate in a general way the performance of the complete unit at the rated ionizer and plate voltage of 10.3 kv. The tape shown in Photograph No. 1 was obtained at a different time than those shown in Photographs No. 2 and 3, but was exposed for an equal length of time, and may be considered as representative for the upstream station. Photograph No. 1 shows many particles under 5 microns in actual size, and a distribution of larger particles up to a few as large as 400 microns, as well as many fibers of lint. (In these photographs, 1/16 inch corresponds to an actual dimension of about 160 microns.) Photograph No. 2, for the tape 15 inches downstream of the unit, shows several large particles up to about 150 microns in size, and a few lint fibers, but very few fine dust particles considering their number upstream of the unit. Photograph No. 3, for the tape 8 ft downstream of the unit, shows an absence of the larger particles of Photograph 2, which apparently settled out of the air stream, although a few fibers of lint remained.

Comparison of the numbers of particles on the upstream and downstream tapes indicates, in an obvious way, a high order of efficiency for the unit in arresting Cottrell precipitate, as is also indicated by the discoloration test results presented in Table 2. The latter results show a considerably higher efficiency for the unit when Cottrell precipitate was being received in the air stream than when the aerosol was outdoor air or kerosene lamp smoke. The overall efficiency of the unit on particles of the sizes found in Cottrell precipitate appears therefore to be better than on the finer particles in outdoor air or kerosene smoke. Nevertheless, the downstream tapes, and the deposits on the after-filter, show that many quite large particles of dust and lint escaped beyond the electrostatic unit. Whether the large particles were passed through the unit because they were not arrested at all, or were caught and later dislodged from the collector plates by electrical sparking, is not known from these tests.

As the photographs show, many large particles and some lint passed unarrested through the after-filter. Assuming that one of the functions of the after-filter is to arrest as much as possible of the material escaping the electrostatic unit, the arrestance characteristics of the after-filter are of major importance in determining the presence, in the air leaving the complete unit, of such particulate matter as is shown in the downstream tape photographs.

No evidence of oil droplet entrainment in the effluent air was observed, either by microscopic examination of the downstream cellophane tapes, or by examination of the test duct downstream of the unit after the tests.

TABLE 1

Face Velocity	Inlet Aerosol*	Ionizer and Plate Voltage	Pressure Drop	Duration of Test	Efficiency
fpm		kv	inch W.G.	minutes	percent
333	A	0	0.120	15	11.1**
333	A	10.3	.120	180	90.0
333	A	10.3	.120	180	90.6
333	A	10.4	.120	180	89.9
266	A	10.3	.085	180	94.1
400	A	10.3	.172	180	87.0
333	S	10.2	.120	30	90.5
333	S	10.2	.122	20	90.5
333	S	10.3	.122	20	90.3
333	C	10.3	.122	8	97.1
333	C	10.3	.123	10	97.5
333	C	10.3	.123	10	97.1

* A = Particulate matter in atmospheric air at NBS.

S = Kerosene lamp smoke in atmospheric air.

C = Cottrell precipitate in atmospheric air
(1 gram/1000 C.F.)

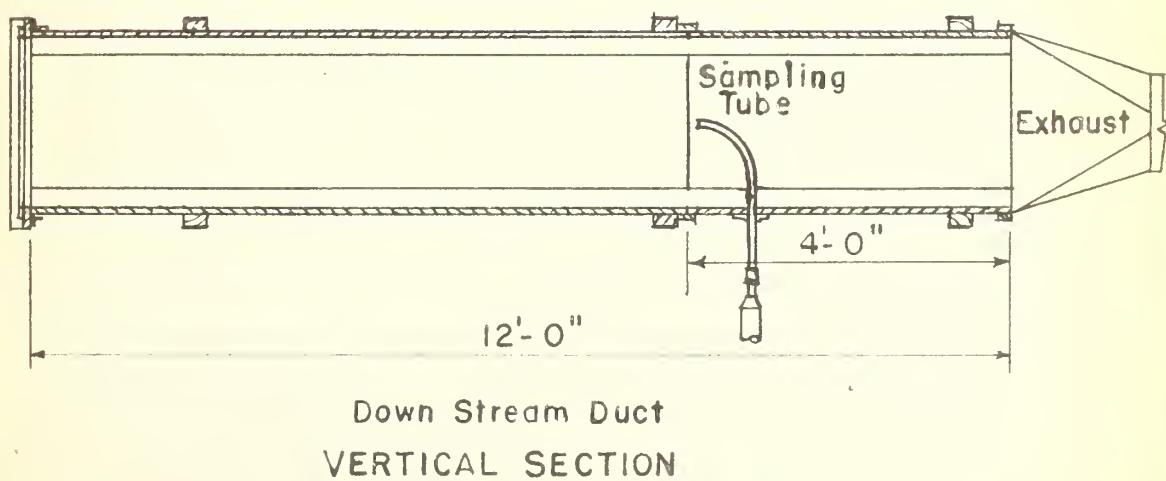
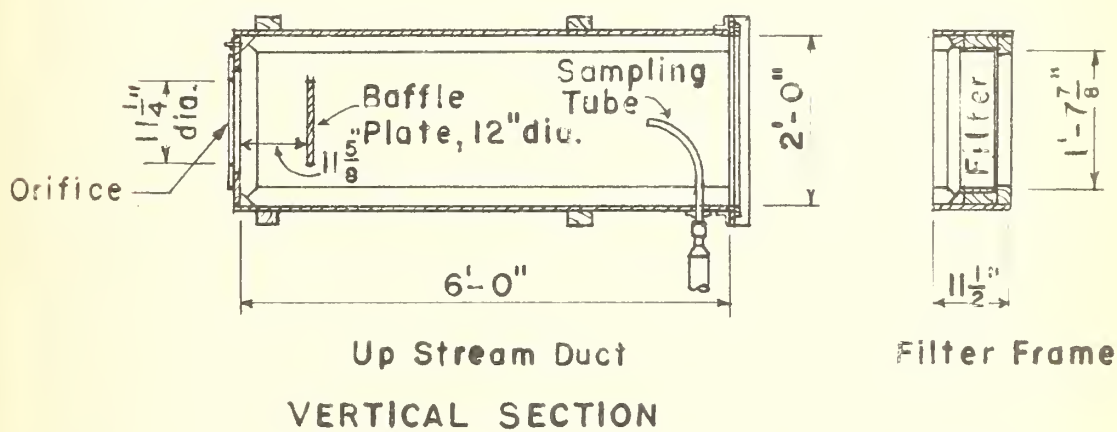
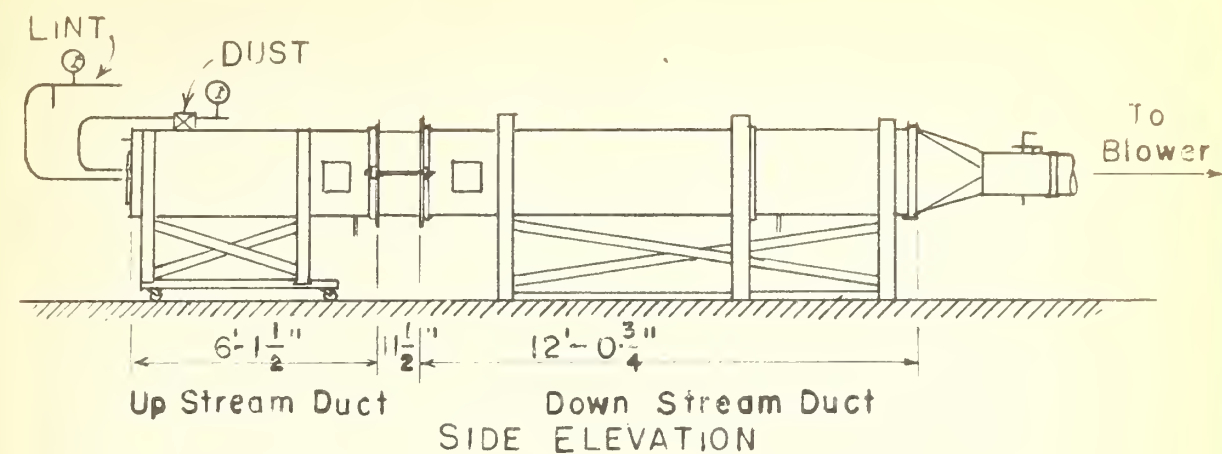
** Since unit was not energized, the efficiency was chiefly that of the after-filter.

TABLE 2

Face Velocity	Dirt Load*	Ionizer and Plate Voltage	Pressure Drop	Efficiency**
fpm	grams	kv	inch W.G.	percent
333	41	10.3	.123	97.2 (avg)
	165	-	.124	97.4
	335	10.2	.127	97.5
	378	8.0	.128	-
	392	(8.3 10.3	.128	96.2
	406	(10.2 8.2	.128	97.2
	476	(7.3 9.2	.129	92.1
(2nd day)	476	10.3	.129	-
	618	10.5	.134	97.0
	703	(7.5 10.4	.141	93.9
	816	6.3	.148	89.0
	901	(7.2 6.3	.155	88.0
		0		

* Average mixture: 3.9% lint, 96.1% Cottrell precipitate by weight.

** Efficiency determined with 100% Cottrell Precipitate.



Air Filter Test Apparatus



Figure 1





Photograph No. 2



Photograph No. 3

THE NATIONAL BUREAU OF STANDARDS

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